USAF Manufacturing Technology

Fall 2000

MT HIGHLIGHTS

Manufacturing Technology USAF

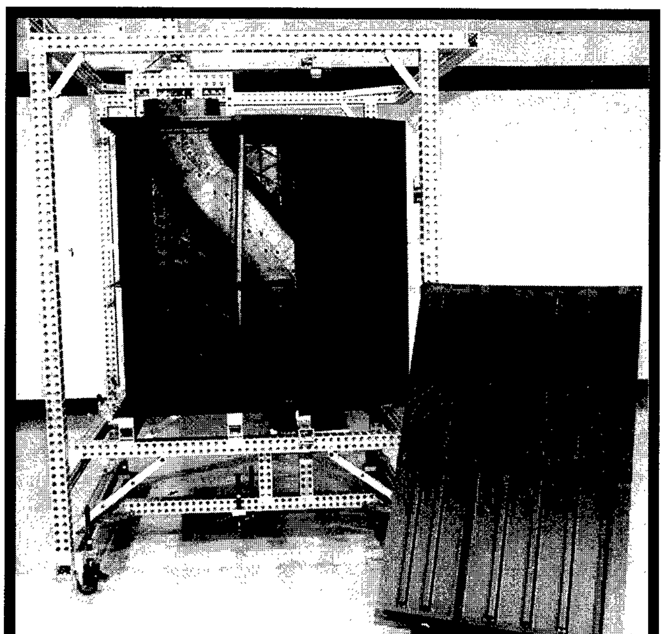
Air Force Research Laboratory • Materials and Manufacturing Directorate • Manufacturing Technology Division
Wright-Patterson AFB, Ohio www.afrl.af.mil

CAI Processes Reduce Weight, Cost, and Assembly Time of Composite Airframe Structures

An Air Force Research Laboratory Materials and Manufacturing Directorate project has achieved breakthrough reductions in the cost, schedule and weight of composite airframe manufacturing.

Developed as part of the "Composites Affordability Initiative" (CAI), these revolutionary design and manufacturing processes used in a demonstration of a forward center fuselage structure reduced the number of parts by 75 percent, and reduced the number of fasteners by 90 percent. The resulting cost avoidance is estimated to be as high as $1.2 million per unit. The project also reduced tooling by 50 percent and flow time by 75 percent.

The costs of advanced composite primary structures for Department of Defense applications generally range from $1,000-$2,000 per pound. The long-range goal of CAI is to reduce the acquisition costs for advanced composite structures by an order of magnitude, or to $100-$200 per pound. With more affordable structures, the use of composites on future DoD weapon systems should increase significantly.



The composite forward center fuselage

The CAI is a collaborative effort between the government and industry to jointly attack the issues and areas of cost associated with the use of composite materials. The Air Force and the Navy are partnering with the four major airframe manufacturers, Boeing, Lockheed Martin, Northrop Grumman and The Boeing Company (formerly McDonnell Douglas), in an effort to jointly develop and mature the essential approaches to achieve major cost reductions in composites.

The composite forward center fuselage created in this effort demonstrated an ability to combine bulkhead and keelhead structures and bond the majority of the assembly. A structure built by these methods would require 1,874 fewer parts, for an estimated savings of $168,660 per unit, and 12,180 fewer fasteners, saving $913,500 per unit. The reduction in part and fastener count would save an estimated 156 pounds over the baseline fuselage. The demonstration was completely assembled in less than two weeks, an estimated reduction of 4,598 man-hours over the anticipated time for fabricating the baseline fuselage structure.

The project used vacuum assisted resin transfer molding (VARTM) to create aerospace quality large integrated structures

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DTIC QUALITY INSPECTED 3

Process Improvements Help Lower Production Costs For Aircraft Gas Turbine Engines

> The Engine Supplier Base Initiative is helping to lower the production costs of gas turbine engines

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Under a cooperative agreement with the Air Force Research Laboratory's Materials and Manufacturing Directorate, Precision Castparts Corporation and Howmet Corporation are helping lower the production costs associated with manufacturing aircraft gas turbine engines.

They are identifying and implementing manufacturing technologies that will streamline the production of cast airfoil and structural components used on those engines. Their efforts will help save the Air Force substantial dollars in overall acquisition costs, improve the industrial base and enhance competitiveness in the gas turbine engine industry.

Gas turbine engines are used on many of today's Air Force and commercial aircraft. These engines are a significant cost factor in the total cost of the aircraft. Anything that can be done to lower the production costs of the engines and therefore lower the overall cost of aircraft will help save the Air Force precious acquisition dollars. That's the objective of the Engine Supplier Base Initiative (ESBI) sponsored by the Materials and Manufacturing Directorate's Manufacturing Technology Division through a cooperative agreement with Precision Castparts Corporation (PCC) of Cleveland, OH, and Howmet Corporation of Whitehall, MI. Four recent successes by PCC offer strong evidence that the ESBI program is significantly shortening the time to implement Air Force-sponsored manufacturing technology improvements.

One project involved replacing the old waxes used to make patterns for castings with newer waxes to improve the dimensional stability, pattern surface quality and dewaxabililty of molds. By balancing the requirements for the various characteristics needed for different parts, the number of waxes required was reduced from five to three. Equipment maintenance was reduced, improved surface quality resulted in a significant reduction in wax repair, and cost savings in excess of $130,000 were calculated for the trial parts alone. The new waxes significantly improved surface finish of the patterns and this translates into less finishing of waxes and castings and better first time yields. These waxes have been extended beyond the test set to approximately 70 additional parts and are being used on new parts.

Another successful effort was the Finishing Reduction Process project for the final machining of ceramic cores used on airfoil castings. Under this project, Computerized Numerical Control (CNC) replaced labor intensive and often inaccurate hand-finishing of the cores. CNC had been used for limited machining of casting airflow features on cores but had not been extended over larger areas. This project extended CNC to finish most of the core. It accomplished its two primary objectives of showing that CNC techniques were capable of reducing finishing labor by 50 percent while improving dimensional accuracy significantly on critical features.

Yet another success under ESBI was the Mold Improvement Project. This project focused on the mold-making operation which impacts surface quality of castings and also influences product yield and repair costs of castings. In the particular instance involved, the castings were requiring excessive repair for rough surfaces. A detailed breakdown of the process was made, the needed process changes were developed on one part number, and these were extended over the total product line.

Finally, PCC developed a new shell system that will significantly reduce the amount of rework required for large structural turbine engine castings such as turbine rear and spoke frames, diffusers, tangential on-board injectors and combustor cases. As much as one-third of the price of a structural casting is due to rework associated with the weld repair of defects in the casting. These defects are often due to the presence of flakes of ceramic shell that erode into the molten metal during pouring and to microporosity associated with solidification. The new shell incorporates an engineered formula for the ceramic slurry as well as many enhancements to the production process, which result in a shell with improved erosion resistance. Based on this success, all new parts and other select current production parts are being tooled to use the new shell.

The ESBI program is helping to lower the production costs of aircraft gas turbine engines. The identification and implementation of new manufacturing processes will help stretch dwindling acquisition dollars for Air Force systems. Cost and cycle-time reductions already achieved through ESBI prove the value of seeking process improvements. As a result of these successes, 65 separate technical activities have been initiated under the ESBI effort at 12 Howmet and PCC sites.

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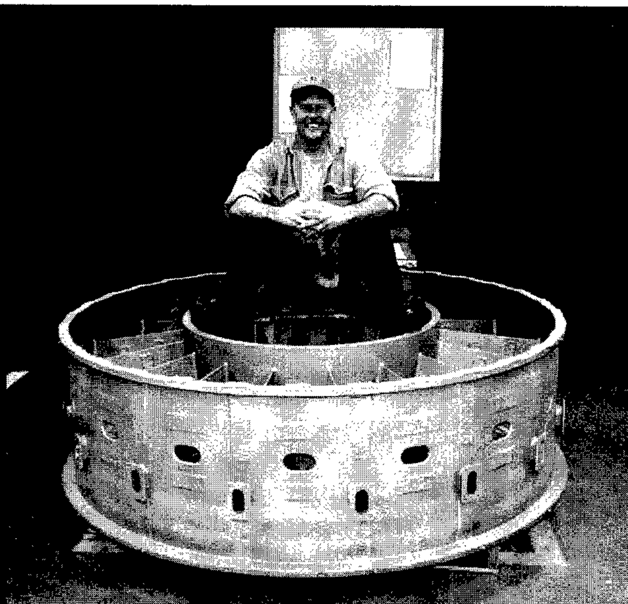

A large engine structural casting of an exhaust frame for an industrial gas turbine.

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Agile Infrastructure for Manufacturing Systems Product Reduces Procurement And Design Cycle Time

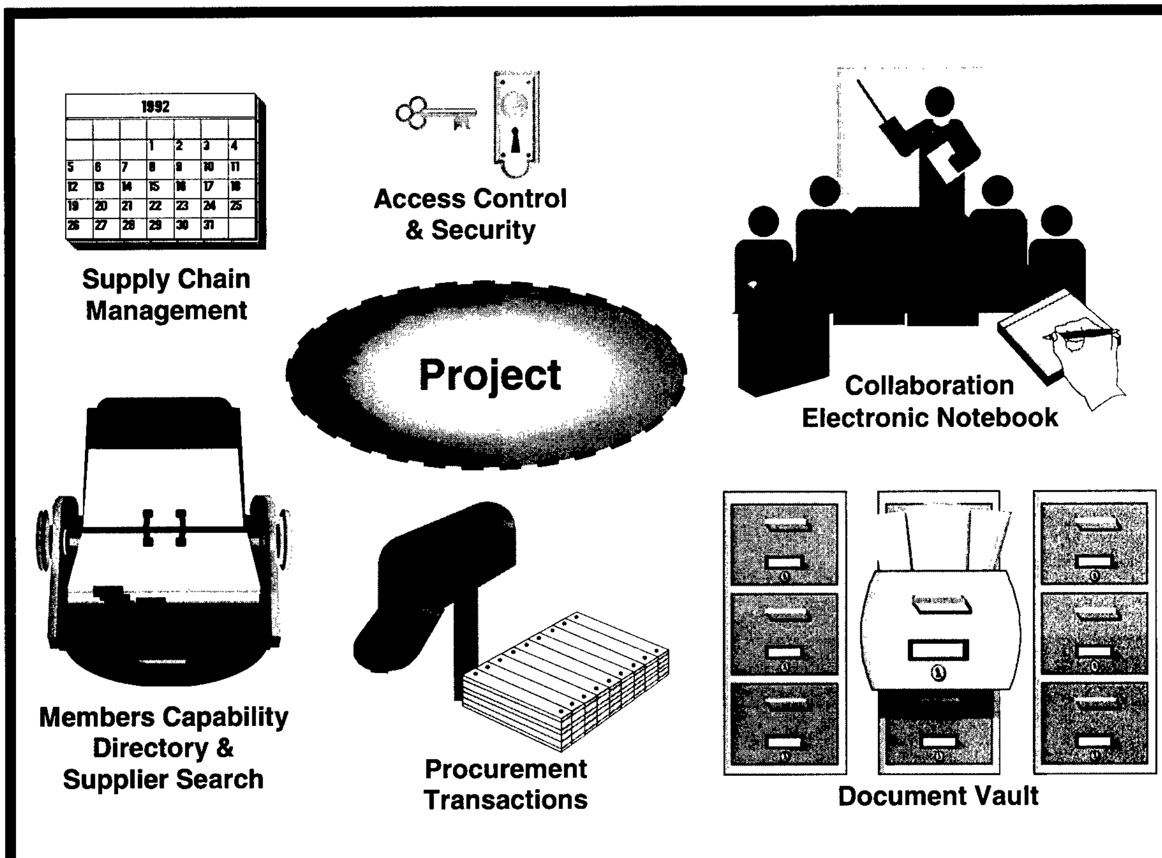
Scientists and engineers at Lockheed Martin Corporation have developed software which enables different companies to operate as a virtual corporation via the Internet.

The work was performed under a cooperative agreement with the Air Force Research Laboratory Materials and Manufacturing Directorate.

The AIMSNet program speeds time to market, facilitates early decisions that guarantee the highest quality levels, and ensures team-wide alignment to product design goals. It reduces product procurement cycle time by 75 percent and design cycle time by 65 percent for complex sub-systems. AIMSNet has been transferred through a commercial product called ipTeamSuite.

Agility in manufacturing is the ability to thrive in an environment of continuous and often unanticipated change. Companies that can reconfigure themselves quickly in response to this change are considered to have agility. Many organizations get this agility by using the internet. A virtual corporation is a coalition of agile organizations that have combined their resources via the internet to produce a particular product at a reduced cost. Companies with complementary roles come together rapidly and quickly dissolve through an electronic commerce environment.

This program, managed by the Materials and Manufacturing Directorate's Manufacturing Technology (ManTech) Division, demon



AIMSNet Modules

strated and evaluated the advanced design, manufacturing, and business transaction processes that enable agility within an organization. One agile manufacturing goal is mutually beneficial best value supplier relationships, and product team integration is a critical component of a manufacturer's business strategy. The Agile Infrastructure for Manufacturing Systems (AIMS) technology, called AIMSNet, provides this integration through a portal to all product development activities, applications, and information, allowing communication and collaboration throughout the product development cycle.

This program focused on the technical and cultural tools necessary to bring agile manufacturing to the aerospace industry. Supplier data requirements, end item data packages, and technical information are being provided through AIMSNet instead of in hard copy. The initiative included "lean manufacturing" emphasis on the streamlined, efficient use of resources and minimizing waste. It also embraced the best commercial quality management practices of customer focus, an empowered and knowledgeable workforce, teamwork, communication, and continuous improvement. It included integrated product/process development and flexible manufacturing capabilities and a networked infrastructure capable of supporting virtual corporations and other agile organizations that can respond to rapidly changing market demands.

AIMSNet facilitates multi-company collaborative design across the supplier chain. It enables companies with different, complementary core capabilities to come together as a virtual corporation, removing roadblocks that hinder rapid and efficient teaming arrangements. It provides savings in cycle time and costs and increases the availability of information from any site. AIMSNet archives corporate knowledge, protects proprietary information, and eliminates supplier uncertainty during product development. It gives manufacturers unprecedented capabilities for effectively evaluating, communicating and collaborating with their suppliers via a secure product development portal.

Using this product, manufacturers can focus on their core competencies and leverage the best external resources to gain significant advances in product design. This program provided: a working virtual corporation prototype; a proven, scalable support architecture; a template for agile business transactions over the internet; procedures and metrics for certifying and categorizing agile suppliers; validated metrics for managing an agile virtual corporation; and a migration business plan for the resulting products.

This ManTech project developed a product, which ensures mutually beneficial best value supplier relationships. Developed to realize the full potential for open, internet-based supply chain integration into the product development process, the AIMSNet technology has been transferred through a commercial product called ipTeamSuite, produced by NexPrise, Inc. It has increased military access to commercial producers and resulted in strategic manufacturing based on "lean production" products and practices.

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AIMSNet facilitates multi-company collaborative design across the supplier chain

20010102 132

Improved Stress Analysis Tools Trim Aircraft Composite Structure Acquisition Costs

. . . this will lead to a 50 percent reduction in fighter airframe acquisition costs.

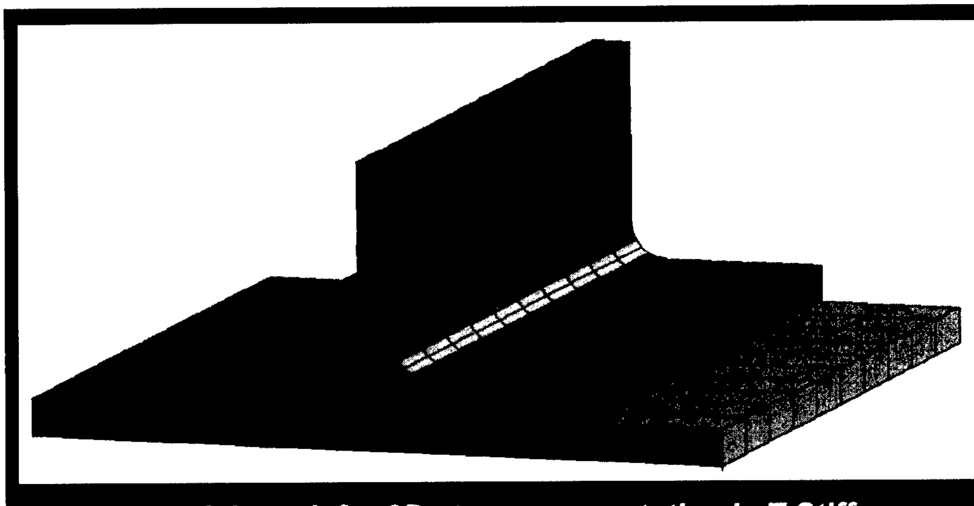
An Air Force Research Laboratory Materials and Manufacturing Directorate project has identified a method for improving the analysis tools used to measure three-dimensional stress in aircraft component structures.

Developed as part of the "Composites Affordability Initiative" (CAI), the approach uses finite element technology in the design process to assist in predicting the performance of innovative bonded composite structures. If successfully applied and coupled with other key technologies, this will lead to a 50 percent reduction in fighter airframe acquisition costs.

The costs of advanced composite primary structures for Department of Defense applications generally range from $1,000-$2,000 per pound. The long-range goal of CAI is to reduce the acquisition costs of advanced composite structures by an order of magnitude, or to $100-$200 per pound. With more affordable structures, the use of composites on future DoD weapon systems should increase significantly. One way to enhance affordability is through the use of bonded and reinforced joints, which requires improved analysis tools for designing and certifying the joints.

The existing industry analysis tool is a one-dimensional tool, which can predict the shear stress in the adhesive, but ignores the peel stresses. Hence, an improved tool is necessary, one that can handle complex three-dimensional (3-D) geometry and recover the interlaminar stresses. Shortcomings currently exist in commercial finite element analysis codes when predicting the 3-D (interlaminar) stress state of 3-D composite structures. Existing codes use plate/shell elements and single-layer brick elements for composite analysis but cannot accurately recover the interlaminar stresses, as the transverse shear strain is assumed to be constant and the transverse normal strain is assumed to be zero. Accurate prediction of the state of stress is necessary to reliably predict failure of traditional laminated composites, as well as the more complex textiles and through thickness reinforced composites.

Small brick element aspect ratio requirements do not accommodate efficient modeling of thin layered structures. Therefore, to accurately compute the interlaminar stress field, brick elements are required with one material ply per brick, thus simplifying the modeling effort. Scientists and engineers supporting the tri-service/industry CAI effort, helped identify an existing finite element capability which, when coupled with a commercial code, can be used to efficiently analyze the stress state of composite structures. After extensive review of the literature, and of existing commercial software, the CAI (Task 5.2) team agreed that the existing ZIG-ZAG finite ele-



Potential mesh for 3D stress computation in T-Stiffner ment technology offered the capability needed. This element is a layered brick, which offers higher-order kinematic behavior with "zig zag" linear interpolation from layer to layer, aspect ratio insensitivity, and can easily handle bending behavior unlike most brick elements.

The ZIG ZAG element is designed to be a composite brick, specifically created for composite stress analysis and fully compatible with commercial finite element software. It is in a mature state, and has already been integrated into a proprietary version of LS-DYNA (explicit finite element code for highly transient wave problems). Following the selection of ZIG ZAG, a family of ZIG-ZAG elements were implemented into the commercial software. A stress post-processor was generated which uses elasticity information such as through thickness equilibrium, exterior surface stress traction conditions and transverse stress continuity conditions to enhance interlaminar stress predictions.

The capability afforded by ZIG ZAG allows accurate modeling and analysis of the more affordable 3-D composite bonded joint concepts, and provides the analysis tool required to determine the limit loads of these structures. Prior to this, the ability to efficiently predict the 3-D stress state in a complex composite structure *did not exist.* This technology is part of a toolbox of technologies necessary to reduce composite structure acquisition costs by half. Savings realized through lower costs could result in significant increases in the use of advanced composite materials in fighter aircraft and other weapons systems, while enhancing composites manufacturing processes, structural reliability and flight safety.

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Low Cost Composite Bonded Wing Achieves Significant Part and Cost Reduction

A new V-22 wing was designed to increase unity and reduce the number of parts fabricated and assembled.

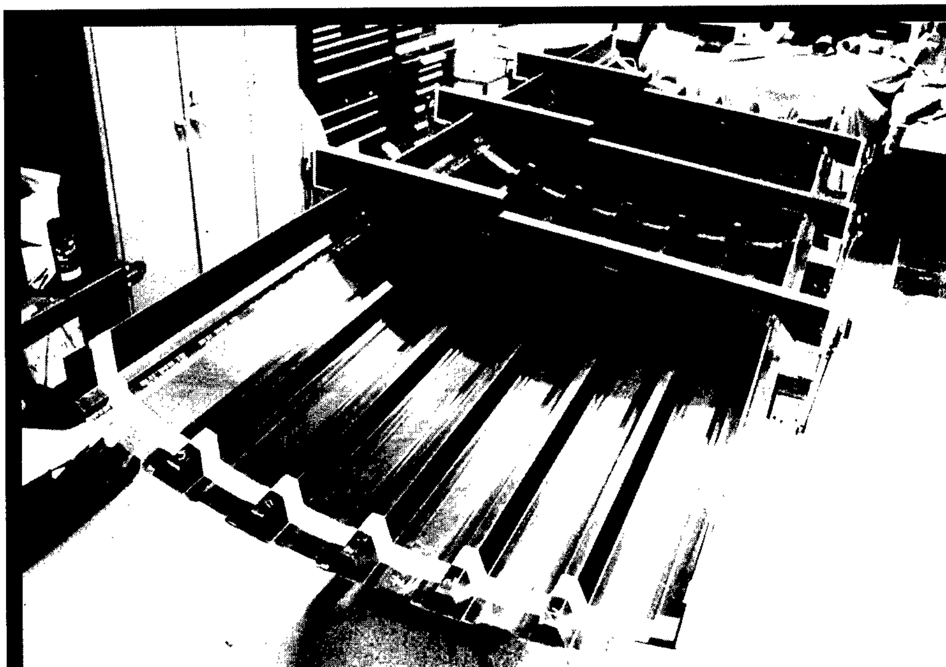
Under a joint project with the Air Force Research Laboratory Materials and Manufacturing Directorate (ML) and Air Vehicles Directorate (VA), both the cost and the number of parts used in a V-22 composite wing box were reduced.

The effort used novel, innovative composite design technologies, materials and manufacturing processes to reduce cost by 50 percent and eliminate 75 percent of the required fasteners.

Future weapons systems will require greater use of composite structures to meet performance and survivability requirements. Acquisition and ownership costs of these structures must be reduced, yet there is little opportunity to do this with existing technologies. Innovative new concepts are therefore necessary, to enhance current composite manufacturing processes.

Under this contract with Textron Corporation (Bell Helicopter Division of Fort Worth, Texas), ML and VA demonstrated that novel materials and manufacturing processes, key to achieving a 50 percent reduction in the cost of a V-22 composite wing, were feasible. The cost and part reduction were achieved through the implementation of novel, innovative, composite design technologies, materials, and manufacturing processes. The resulting simplified structural assembly eliminated the cost drivers and reduced cost by 50 percent; eliminated 75 percent of the fasteners in the baseline article, thereby reducing associated material, installation and inspection costs; and introduced no weight or performance penalties.

A new V-22 wing was designed to increase unity and reduce the number of parts fabricated and assembled. Detail concepts were developed to make maximum use of composite materials properties. Through the use of a concurrent engineering/integrated product development concept, the program success-



A conformal fabric composite rib chord, fabricated through resin transfer molding, is adhesively bonded to the wing skin and pultruded rod reinforced hat stiffener. These are several of the key design and manufacturing features implemented in the redesign of the V-22 wing.

fully demonstrated the implementation of nascent designs, analysis, and manufacturing technologies.

The Bell concept implemented extensive use of adhesive bonding of pre-cured components in a primary structure. Resin transfer rib webs were bonded to the hat stiffened skin. Bond line tolerances were loosened to simplify assembly. This tolerance change had no significant impact on strength or durability. Other notable changes included use of a wing skin laminate that was designed to increase the automatic tape laying machine efficiency. Besides this, a new material form called pultruded rods, was also implemented. These high stiffness, carbon graphite fiber rods, served to recover the bending stiffness characteristics in the wing. The V-22 demonstration article was tested for sufficient strength, stiffness, durability and damage tolerance at the Air Force Structural Test Laboratory.

This program was one of the Design and Manufacture of Low Cost Composite programs, which developed the technology essential to the cost reduction of wing, fuselage, and engine structures for future aircraft. Assembly costs were significantly reduced and overall cost reduction goals were exceeded. Design and manufacturing concepts developed in this program, particularly the bonded rib to skin interface, have transitioned to the Bell 609 commercial tilt-rotor and are being further developed for possible future use in the V-22.

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(no autoclave was needed to cure the structural parts). Low temperature paste adhesive bonding helped to reduce shimming. Localized heating and pressure were used for bonding in place. Low temperature tooling materials simplified the assembly process and reduced tooling costs. Fiber-placed Iso-grid structures demonstrated automated fabrication of stiffened structures. This reduced the cost and time required for automated layup.

The processes and technologies demonstrated in this project reduced assembly time, weight, cost and waste in the production of a forward center fuselage. This is part of a toolbox of technologies necessary to reduce composite structure acquisition costs. Savings realized through lower costs could result in significant increases in the use of advanced composite materials in fighter aircraft and other weapons systems enhancing performance, structural reliability and flight safety. If successfully applied and coupled with other key technologies, this will lead to an order of magnitude cost reduction in fighter airframe structures.

For more information, contact the ManTech Technology Information Center at techinfo@wpafb.af.mil or (937) 256-0194 Refer to item 00-248

Title III Initiative Expands Domestic Production Capacity for Indium Phosphide Wafers Used in Defense Electronic Systems And Saves $35 Million

The...project will have a far-reaching impact on the Air Force, the DoD, and the consumer.

An effort managed by the Title III Program Office at the Air Force Research Laboratory's Materials and Manufacturing Directorate has established a viable, long-term domestic manufacturing capability for indium phosphide wafers used in military electronic systems. The project will save an estimated $35 million in the production of weapon systems vital to the nation's security.

The Defense Production Act was enacted in order to assure a domestic source of strategic materials. Title III of the Act enables investment by the Department of Defense to establish necessary production capacities. The Indium Phosphide (InP) Wafer Project was designed to accelerate the insertion of InP technology, expand production capacity, improve quality, increase diameter, and lower wafer production costs. It sought to establish viable, long-term, world-class domestic manufacturing capabilities in support of both military and commercial requirements.

Electronic defense applications requiring ultra high-speed operating frequencies (seekers and battlefield radar), lower power consumption (satellite crosslinks and battlefield communication systems), and exceptional low noise performance are being greatly improved with InP technology. The project also has a major impact on consumers, as high-quality, affordable wafers are used to support next-generation wireless consumer products, greatly enhancing telecommunication speeds.

The Title III Program Office awarded contracts to American Xtal Technology (AXT), of Freemont, CA, and M/A-COM, Inc., of Lowell, MA. Initial technical efforts focused on process improvement, material evaluation and qualification, 100mm (four-inch) process development, capacity expansion, strategic planning and marketing, and production cost reduction. Each company implemented a quality system compliant to the International Standards Organization (ISO) standards and subsequently received ISO 9000 certification for their vastly expanded InP production operations. Funding provided by Title III provided an incentive for each contractor, who focused on specific processes which could best benefit from needed investment.

M/A-COM, who was well experienced with high-pressure czochralski crystal growth from its gallium arsenide (GaAs) product line, was able to develop mature indium phosphide crystal synthesis and wafer shaping processes, essentially from scratch. Upon conclusion of the Title III program, M/A-COM's InP wafer shaping and polishing operations were achieving yields comparable to that of its highly mature GaAs product line.

AXT chose a much different technical approach, focusing its technical efforts on enhancing its existing vertical gradient freeze (VGF) crystal growth technology. Under prior AFRL funding, AXT demonstrated the applicability and scalability of VGF growth technology to InP synthesis. They built upon this early developmental work and made very dramatic progress in becoming an acknowledged leader in the manufacture and supply of low-defect, large diameter InP wafers. In conjunction with its Title III contract, AXT has assumed a world leadership position as a supplier of 100mm InP wafers. This achievement is particularly significant because the merchant availability of 100mm material is critical to the continued acceptance and use of indium phosphide by commercial suppliers. AXT increased its InP wafer sales by more than 15 times, achieving a worldwide market share of more than eight percent.

With the introduction of the first, high-volume, commercial applications of InP anticipated in 2002, AXT and M/A-COM are well positioned to continue this growth as key suppliers to both defense and commercial product lines. Each company relied heavily on a combination of yield improvements and equipment purchases to more than quadruple their growth capacities. AXT's crystal growth yields more than doubled while M/A-COM was able to develop and demonstrate a stable production process capable of manufacturing more than 50,000 square-inches of InP material annually. Personnel from the Title III Program Office were members of the project team and contributed to the success of the project.

The Indium Phosphide Wafer Project will have a far reaching impact on the Air Force, the DoD, and the consumer for several years to come. The Title III contracts and the ISO 9000 certification significantly impacted the success of this effort, which reduced the prices on InP wafers by 30 percent, and increased the companies global market share to more than a combined 17 percent. The DoD now has two reliable domestic sources for producing high quality InP products at lower prices, while commercial users of InP wafers are reaping gains in size, quality, and price.

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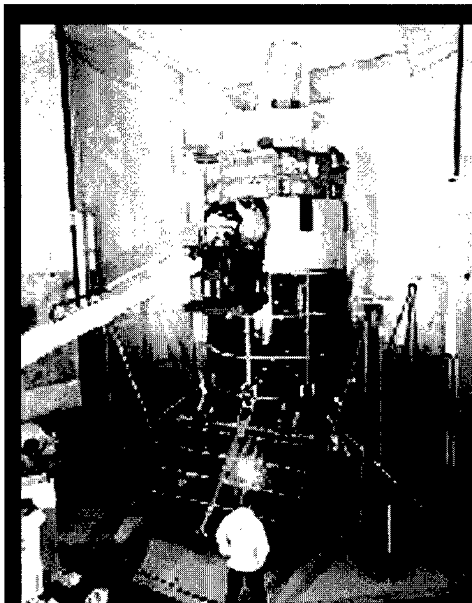
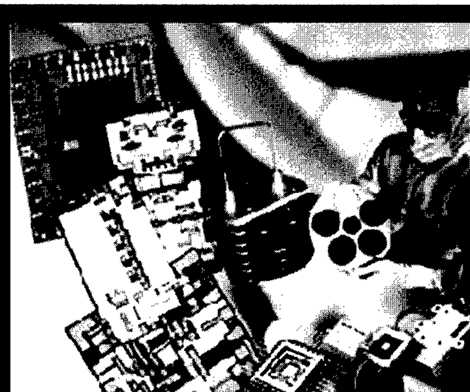




(Above) An array of Indium Phosphide devices and wafers (Left) TRW satellite employing Indium Phosphide wafers.

Casting Supplier Initiative Reduces Cost of Aircraft Gas Turbine Engines

Four projects have improved processes improved quality, reduced scrap and reduced cycle time...

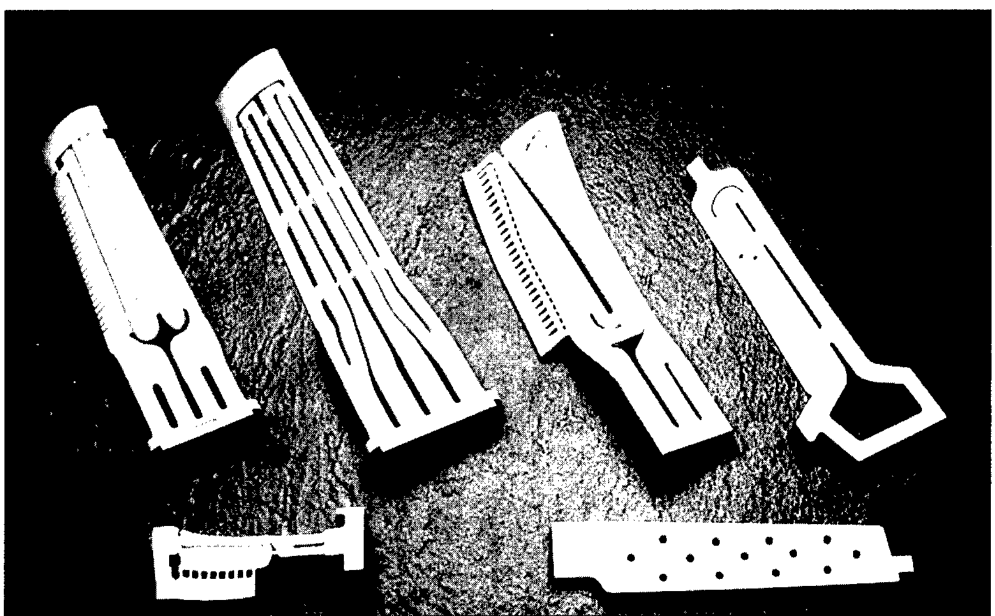
Under a cooperative agreement with the Air Force Research Laboratory's Materials and Manufacturing Directorate, Howmet Corporation and Precision Castparts Corporation are significantly lowering the cost of manufacturing aircraft gas turbine engines.

Four projects have improved processes, improved quality, reduced scrap and reduced cycle time in the manufacture of these engines. Greater improvements are anticipated as the projects continue.

Gas turbine engines are used on many Air Force and commercial aircraft. They are a significant part of the total cost of these aircraft. The Engine Supplier Base Initiative (ESBI), also known as the Casting Supplier Initiative, was established to identify and implement manufacturing improvements in a key portion of the gas turbine engine industry. Sponsored by the Materials and Manufacturing Directorate's Manufacturing Technology (ManTech) Division, the ESBI targets cost and cycle time reductions in the manufacture of cast airfoil and large structural components for these engines. Reductions are achieved by implementing technical advances in foundries which make the engines.

As part of the Casting Supplier Initiative, Howmet's Morristown Casting Support Facility, in Morristown, TN, is conducting a set of projects that dramatically impact the cost and quality of ceramic cores used to create engine castings. Four of these projects have shown significant benefits and there is strong evidence that they will provide more benefits in the future. The benefits come through improvements in core manufacturing operations which result in casting product improvements — better cores provide better castings.

Better core dimensional control leads to improved casting dimensional control, reduced scrap, reduced core breakage during wax injection, and an ability to tighten casting tolerances. The Core Dimensional Improvement project has a goal of reducing the standard deviation of the fired core contour by 50 percent. Reducing this characteristic will lead to less dimensional scrap and lower prices. As a result of several process improvements, the standard deviation has been reduced by ap-



Ceramic cores prepared at the Morristown casting supply facility

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proximately 35 percent so far, and the remainder of the goal is expected to be achieved through continuous improvement efforts.

The Reduction in Broken, Cracked and Chipped Cores project is trying to reduce core breakage by 50 percent over the life of the program. A continuous improvement project is attempting to reduce trailing edge cracking by identifying the root cause and removing it. Work is also underway with casting foundries and engine builders to improve visual tolerances and to define improved techniques for detecting cracks in cores. One of the activities is showing the ability to reduce cracking during the core-firing phase, having already improved by 30 percent, with additional improvement anticipated. In the future this project will evaluate reducing die fill pressures and speeds during the molding cycle, developing alternative die release procedures, and use of modeling software.

The Reduction in Compound Thermal Variation project is trying to reduce dimensional and visual variation in raw materials, batched materials, and thermal treatments by a minimum of 25 percent per year. By installing new preheating units, modifying transfer molding compounds, and working with key raw material suppliers on delivery, quality, service and price, a 48 percent improvement has been achieved in this area. Continued improvements are expected to come from a new roll mill, better tailoring of material properties and other processing enhancements.

The Cycle Time Reduction project has achieved an impressive 39 percent reduction in shop-wide cycle time as a result of cell balancing, scheduling and buffering refinements, and one piece flow concepts. Inventory has also been reduced and future improvements will be sought in the scheduling system and by reducing the number of pre-bake cycles.

The steady flow of product and process improvements and cycle time reductions show that the ESBI program is a tremendous success. The core savings on Air Force parts alone have already saved more than the total sum of ESBI dollars invested at the Morristown Casting Support Facility. The benefits from the ESBI are significantly greater when looking at the full spectrum of projects at the 12 Howmet and Precision Castparts Corporation sites actively involved in the casting operations portion of this program.

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HIGHLIGHTS

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End of Contract Forecast

October 2000	X-Ray Sensors for Real Time Control of Thin Film Deposition F33615-99-C-5702	Technology Assessment & Transfer Incorporated, Annapolis, MD
October 2000	Concerning the Composites Affordability Initiative (CAI): Phase II - Pervasive Technology/Seattle F33615-98-3-5103	Boeing Company, Defense & Space Group Seattle, WA
October 2000	Manufacturing Technology for Multifunctional Radomes F33615-93-C-4312	Lockheed Martin Corporation Palmdale, CA
October 2000	Lean Blade Repair Pilot F33615-93-C-4301	General Atomics Corporation San Diego, CA
November 2000	RASSP Approach to Legacy Electronics F33615-98-C-5130	VP Technologies Marietta, GA
November 2000	Conformable Multichip Assembly Technology F33615-98-C-5149	Epic Technologies Incorporated Woburn, MA
November 2000	Hybrid Composites Manufacturing Technology for Braiding/Filament Winding F33615-98-C-5153	A&P Technology Incorporated Covington, KY
November 2000	Remarkable Material for Advanced CMC Propulsion Systems F33615-98-C-5157	Ceramic Composites Incorporated Millersville, MD
November 2000	Advanced Reconfigurable Machine for Flexible Fabrication F33615-95-C-5500	Lockheed Martin Corporation Palo Alto, CA
December 2000	Aluminum Metal Matrix Composites Multiple	Advanced Refractory Technologies Buffalo, NY
December 2000	The Control Stick of the 21st Century F33615-00-C-5518	Essex Industries Incorporated St. Louis , MO
December 2000	The Control Stick of The 21st Century F33615-00-C-5519	Stirling Dynamics Incorporated Seattle, WA
December 2000	Parts Obsolescence Management Technology Transition (POMTT) F33615-99-2-5502	Lockheed Martin Corporation Orlando, FL
December 2000	Affordable Tool-Less Edge Fabrication F33615-99-C-5314	Lockheed Martin Corporation Marietta, GA
December 2000	Parts Obsolescence Management Tools F33615-98-C-5147	i2 Technologies Incorporated Dallas, TX
December 2000	Breathable Release Coatings for Ceramic Tooling F33615-98-C-5159	Utility Development Corporation Livingston, NJ

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Fall 2000

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